Randy Scheib
Regional Technical Sales

Southeast

Region

Introduction to TOfD & Phased Arrays Industrial Applications

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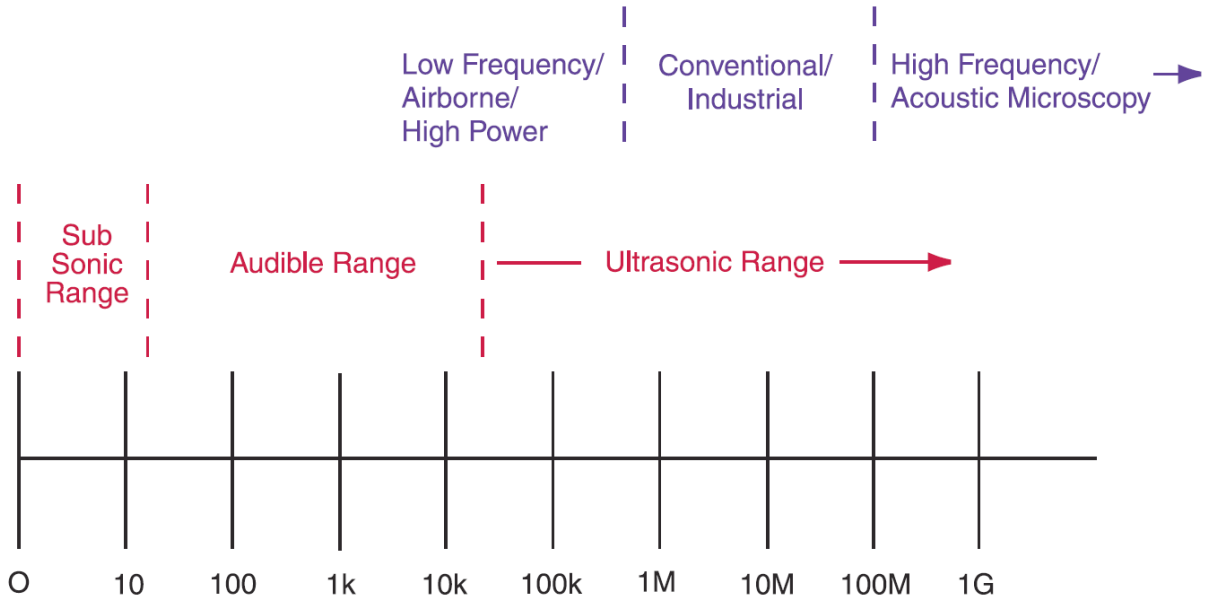
What is an Ultrasound ?

Ultrasound is defined as any sound that is above the range of human hearing.

This Human limit is 20 KHz



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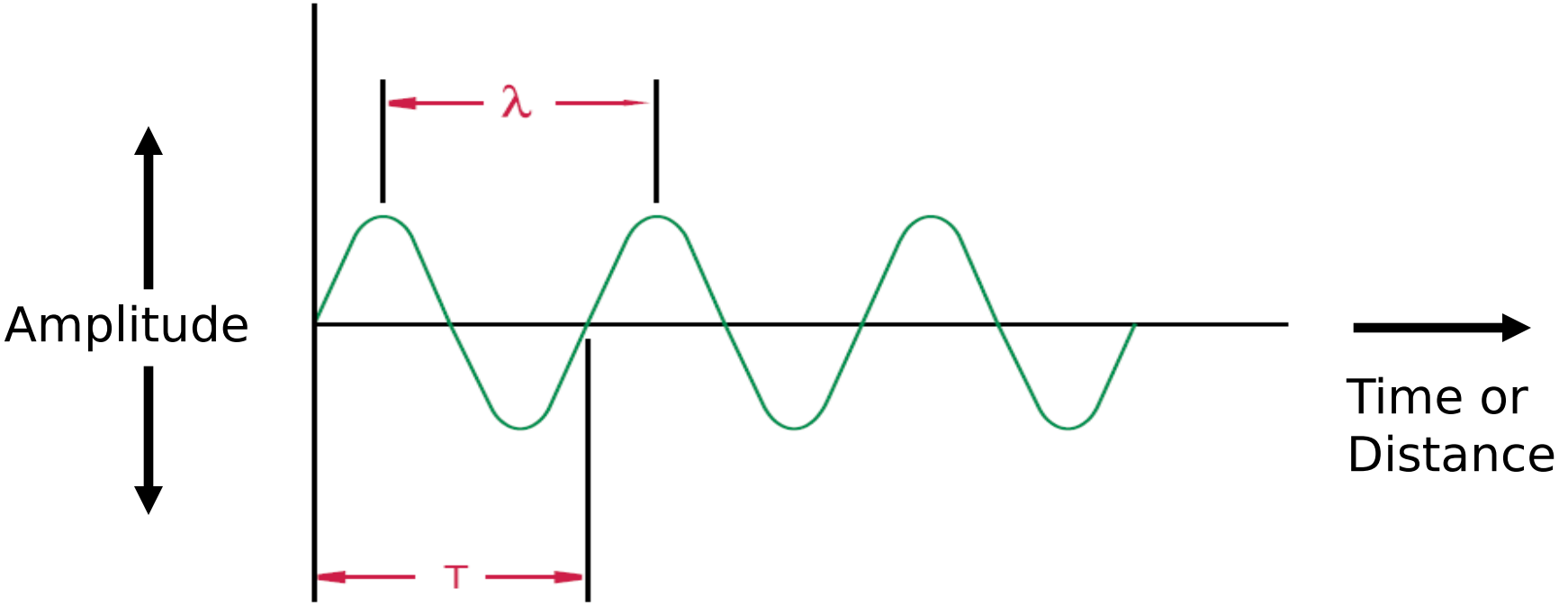
What is an Ultrasound?

Ultrasonic vibrations travel in the form of a wave.
The basic parameters of a continuous wave include
the wavelength (λ) and the period (T) of a complete cycle



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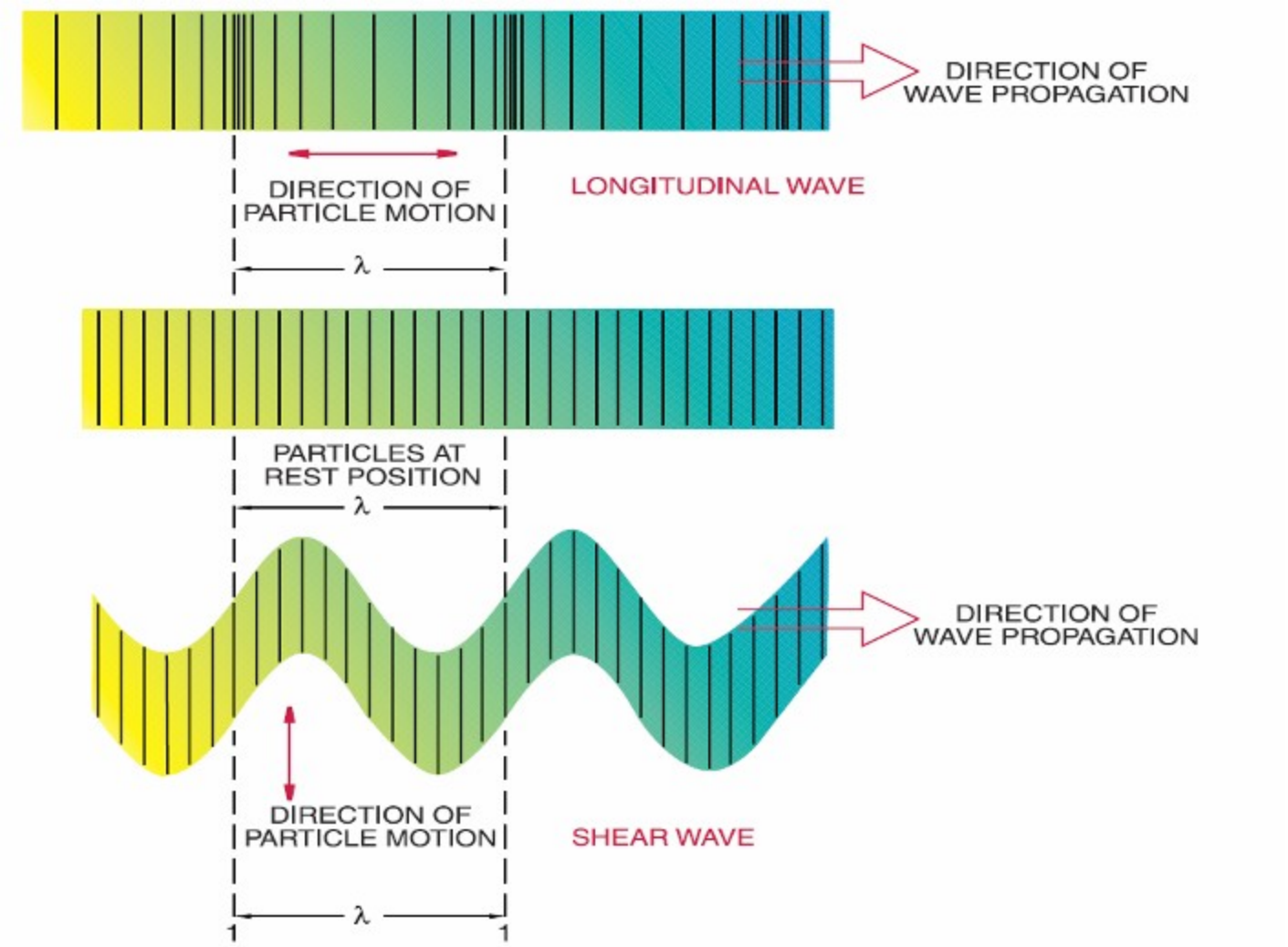
Properties of Sound Waves



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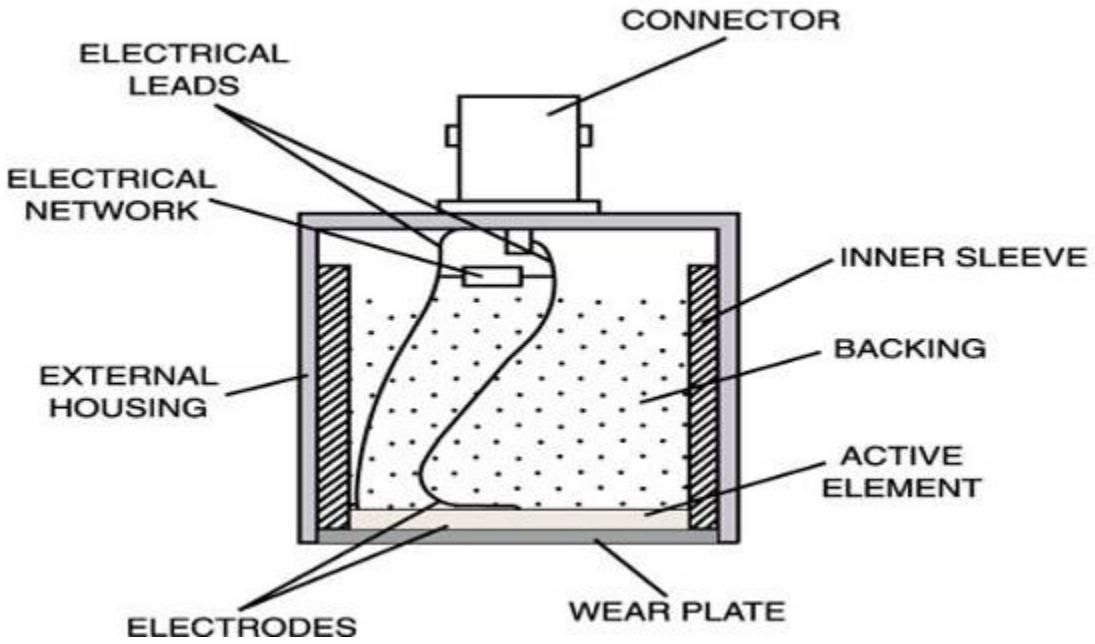
What is an Ultrasonic Transducer?

- A Transducer by definition is a device that converts one form of energy into another form of energy
- An Ultrasonic transducer takes a high voltage/low amperage electrical pulse and converts it into the mechanical energy of an Ultrasonic transmission. This device can also work in reverse



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What is TOFD?

- Time-Of-Flight Diffraction (TOFD) relies on the diffraction of ultrasonic energies from 'corners' and 'ends' of internal structures (primarily defects) in a component being tested.

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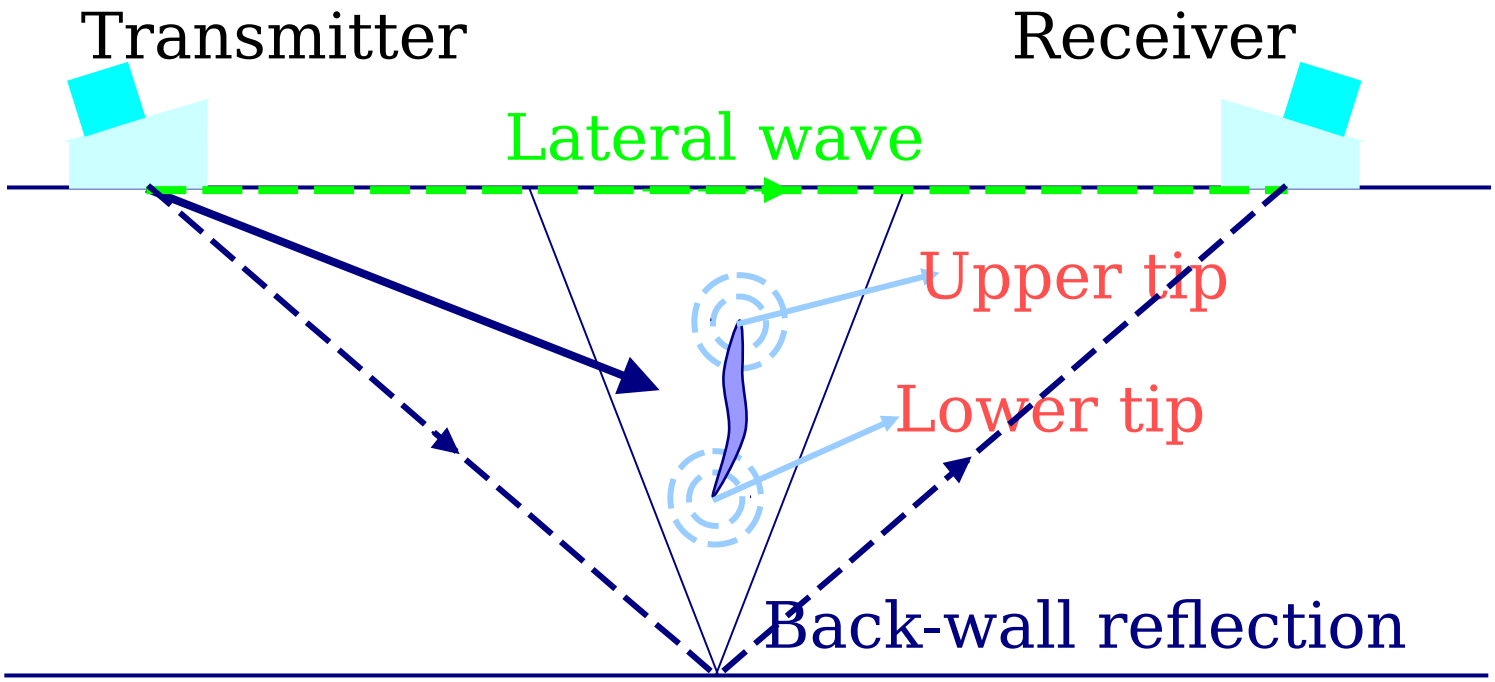
TOFD Signals



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TOFD History

- Developed in UKAEA Harwell in ~70's
- Manufactured commercial Zipscan
- Used very effectively in nuclear PISC II and DDT trials
- => Showed good detection and excellent sizing
- Recently "adopted" by petrochemical and other industries

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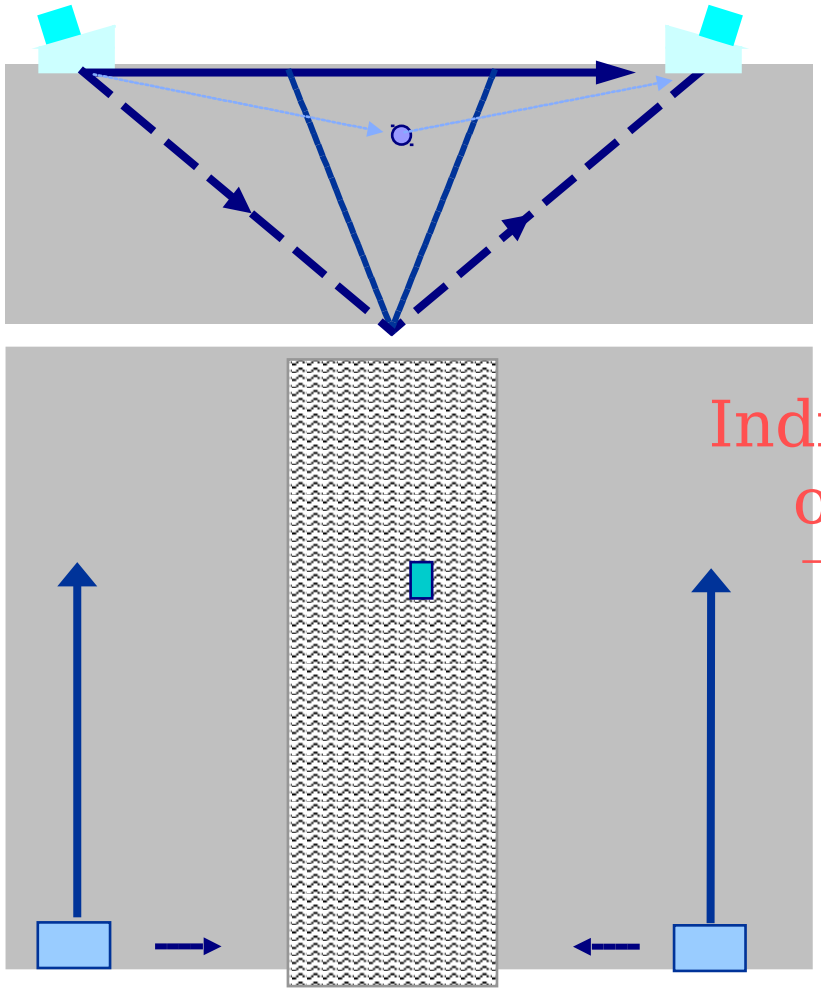
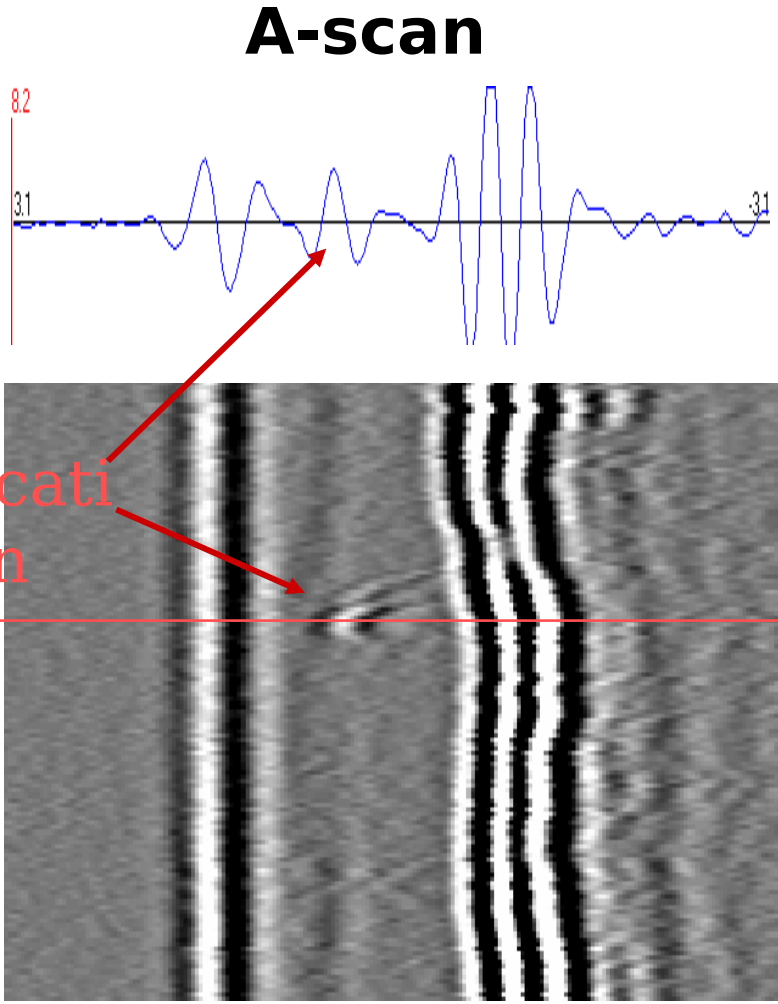
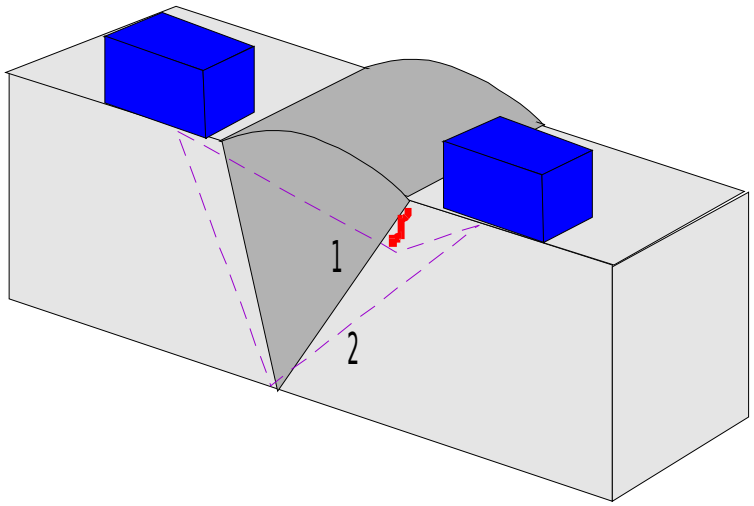
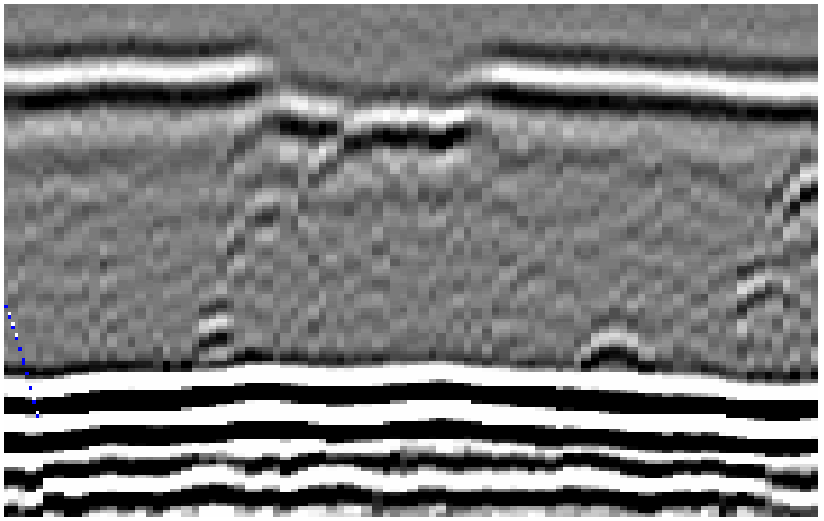
Data Visualization (TOFD)

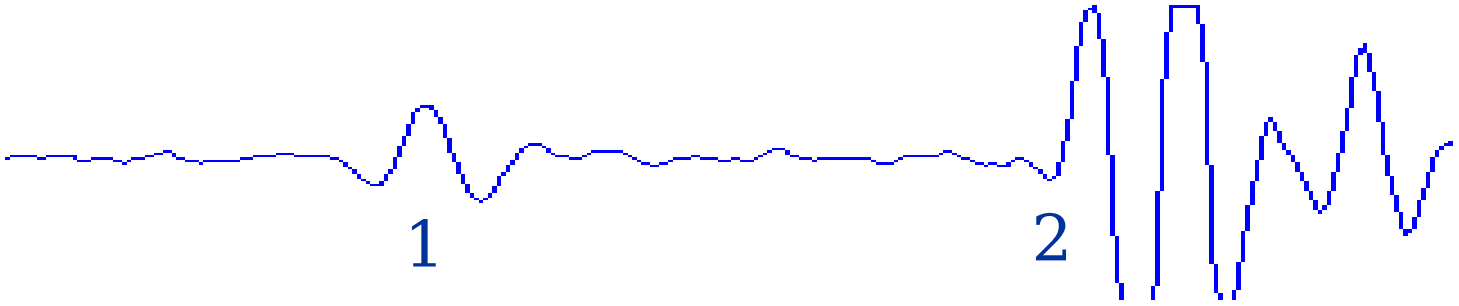




Near Surface Crack







The crack blocks the Lateral Wave
And the lower tip appears on the A-scan

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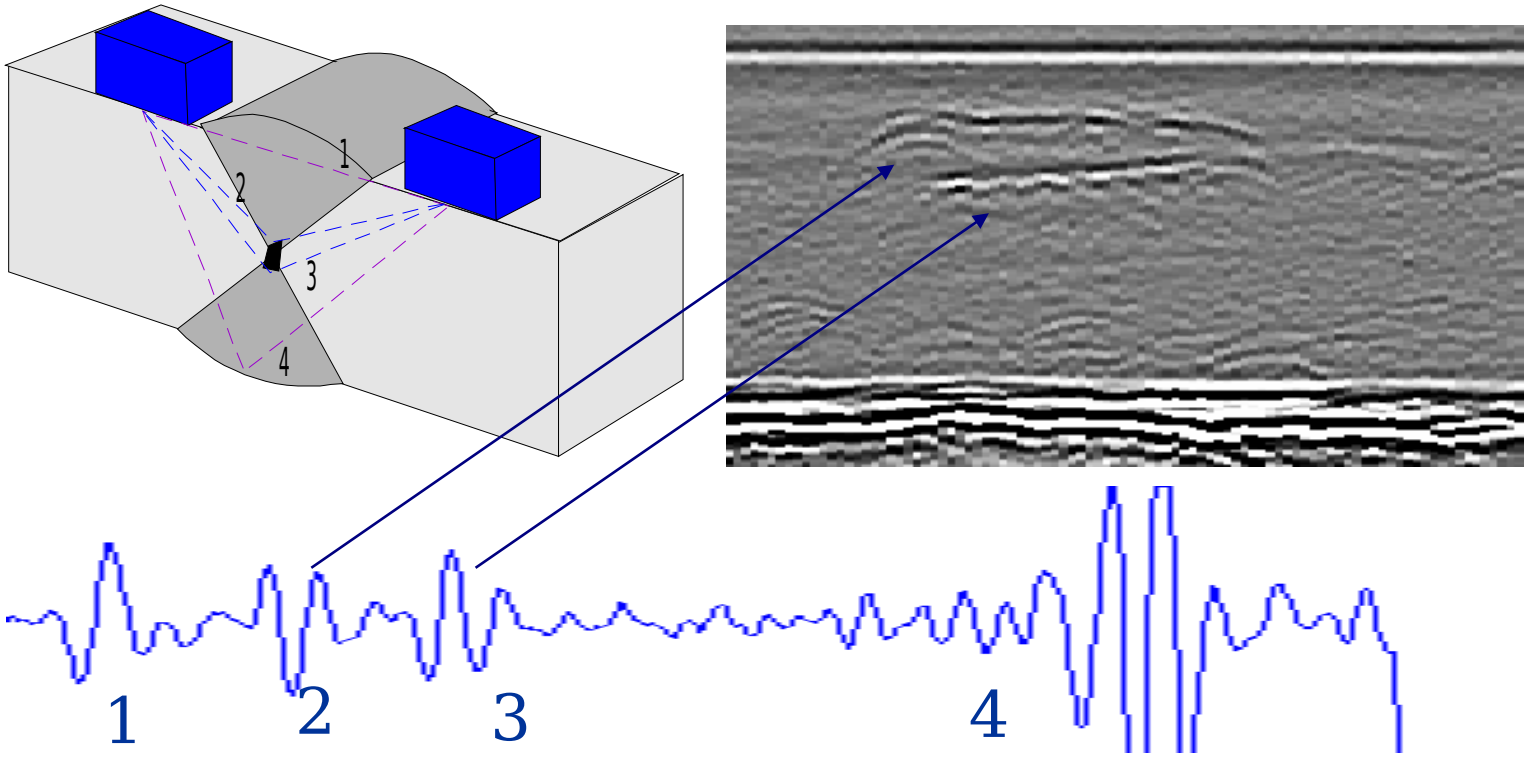
Incomplete Root Penetration



Note the two signals from the top & bottom

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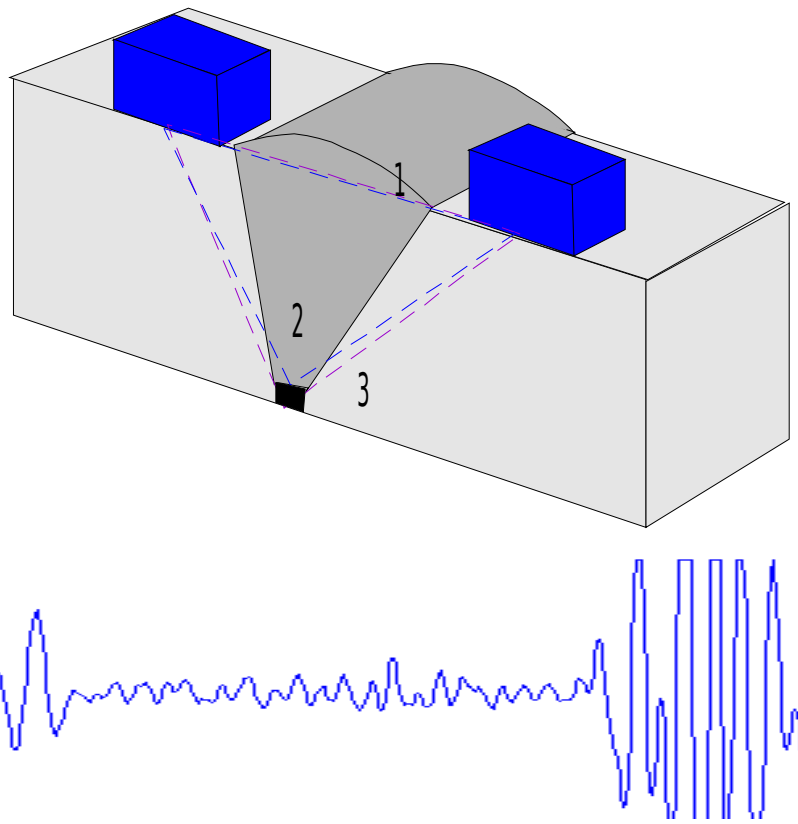
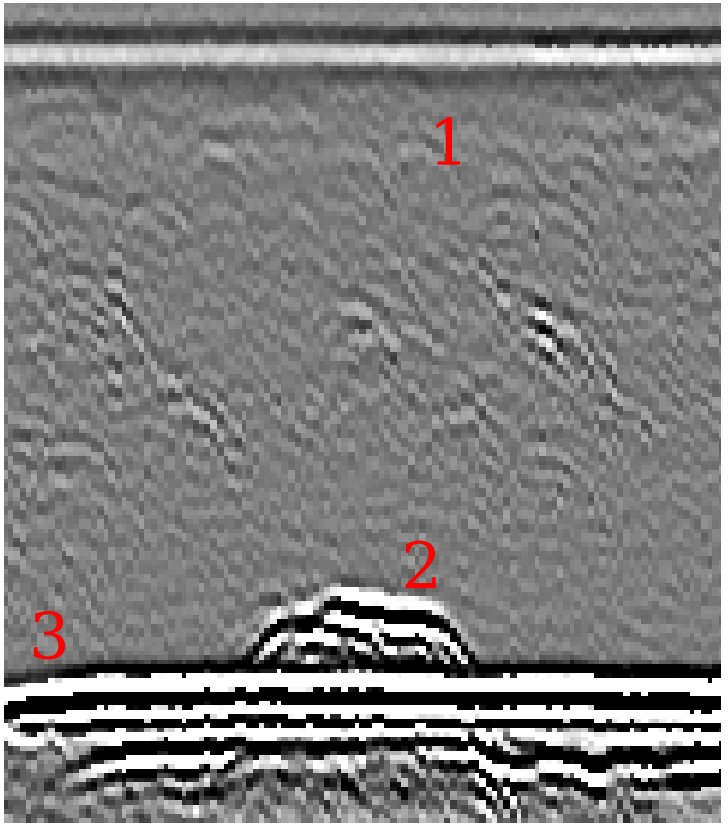
Lack of Root Penetration





Note the inverted phase between LW and defect

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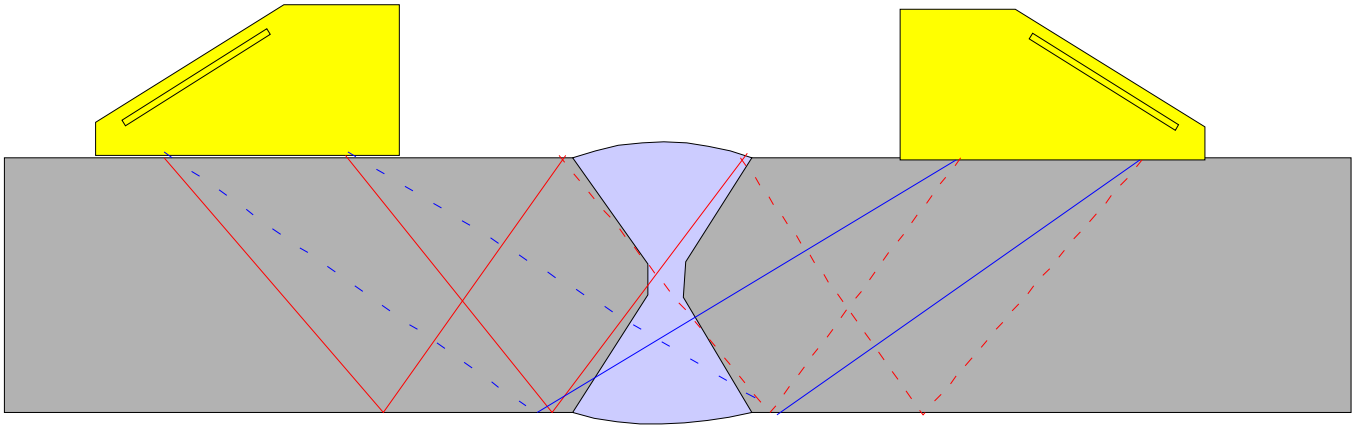
Technique Description
Phased Array (combined scan)



This configuration allow the inspection of the weld without removing the Cap

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Technique advantages

- The inspection is done in a single pass → Fast scanning
- TOFD → High precision sizing technique
- Real time A,B, and C-Scan imaging
- Quick defect evaluation by clear imaging
- PA→ Lateral position of defect
- PA→ Focus Depth adjustable
- Complete aproach because of combination of
  2 techniques: TOFD and Phased Array

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Introduction to Phased Array

The implementation of high speed electronics, real time imaging, and composite probe development.

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Phased Array Definition

- A mosaic of transducer elements in which the timing of the elements' excitation can be individually controlled to produce certain desired effects, such as steering the beam axis or focusing the beam.

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Key Concept

- Phased arrays do not change the physics of ultrasound
- PA's are merely a method of generating and receiving a signal
- If you obtain X dB using frequency Y with conventional UT, you should obtain the same signal amplitude and frequency response using PA's.

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How Phased Arrays Work

- Ultrasonic phased arrays consist of a series of individual elements, each with its own connector and time delay circuit.
- Elements are acoustically insulated from each other.
- Elements are pulsed in groups with pre-calculated time delays for each element, i.e., “phasing.”

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Design Parameters of Phased-Array Probes

- A linear array (1D) is basically a long conventional probe…

- Cut in many small elements, that can be individually excited.

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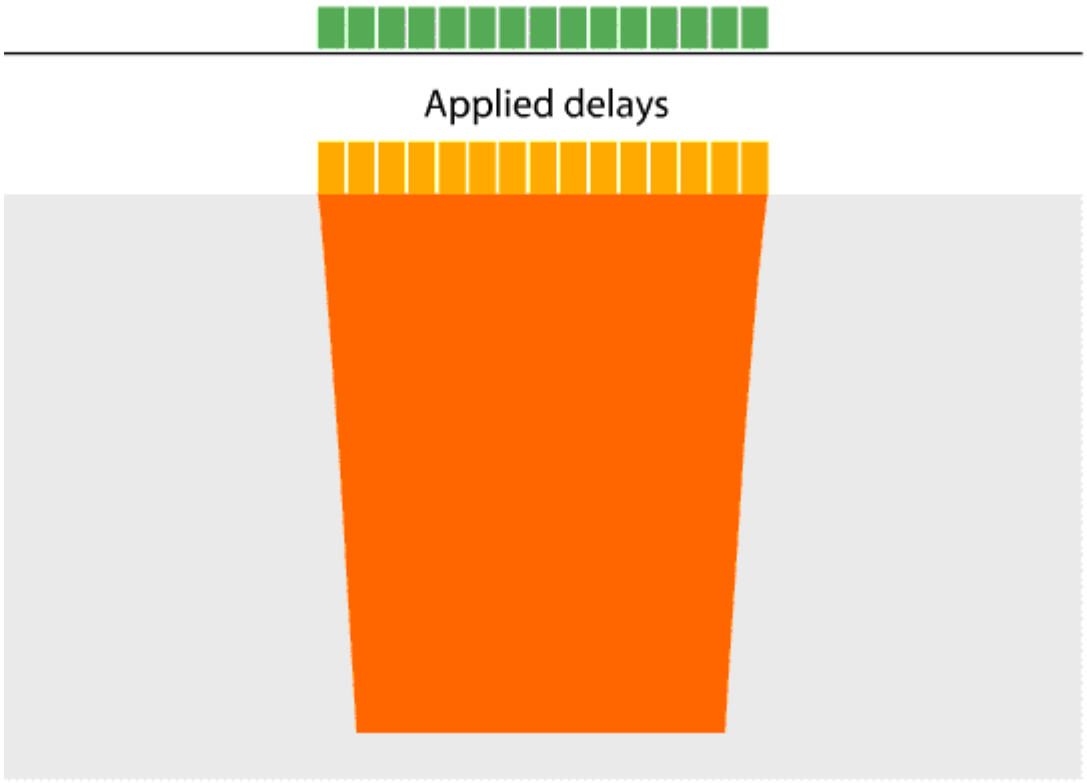
Beam Focusing



- large range of focal depth (focusing)
- adjustable each pulse.

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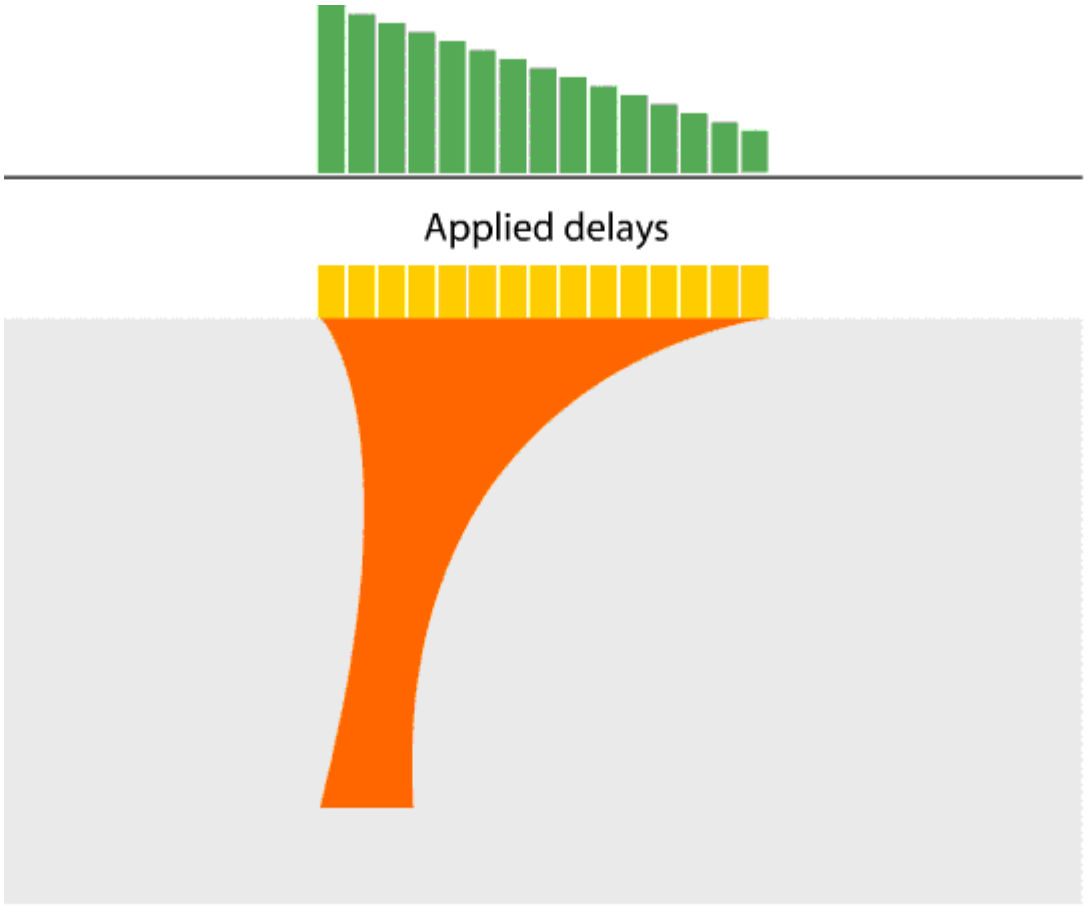
Beam Steering



- large range of inspection angles (sweeping)

- multiple modes with a single probe (SW, LW)

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Phased Array Probes

- Linear arrays are the most common type and can perform scanning in one dimension or plane
- Matrix arrays can scan in two dimensions, and offer considerably more flexibility but add a considerable amount of complexity
- Circular and sectorial-annular arrays are specific for normal beam inspections, e.g., billets, forgings.

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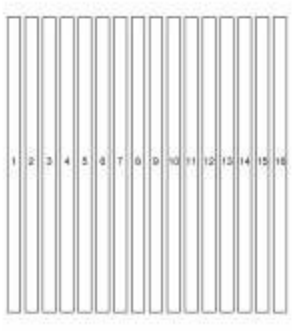
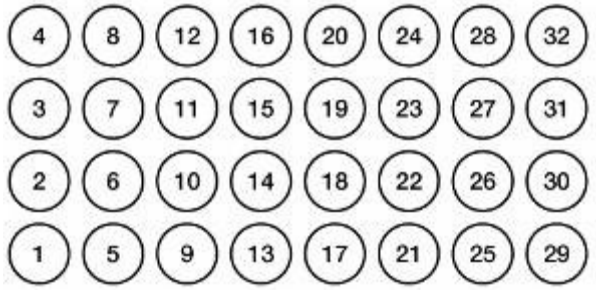
Common Probe Geometry

Linear

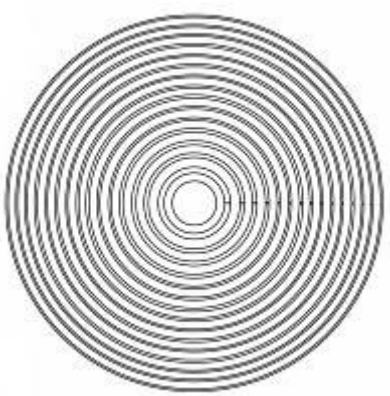


1D linear array



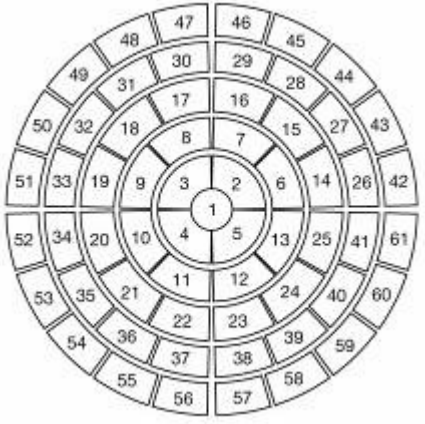
2D matrix

Circular



1D annular array

annular



2D sectorial

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Focal Law

- An internal or external calculator produces a file called a

  FOCAL LAW

- The Focal Law defines the elements to be fired, time delays, and voltages for both the transmitter and receiver functions.

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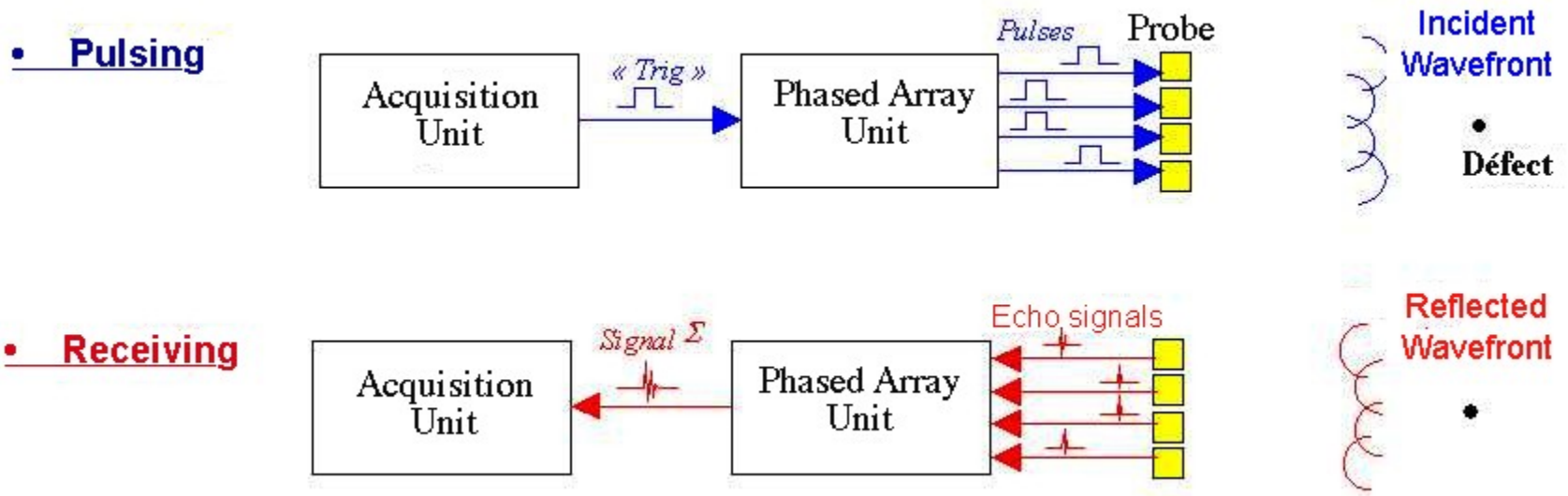
Pulse – Receive Physics



Beam forming or focusing requires precise pulsing and time delays. The exact opposite timing is required when Receiving.

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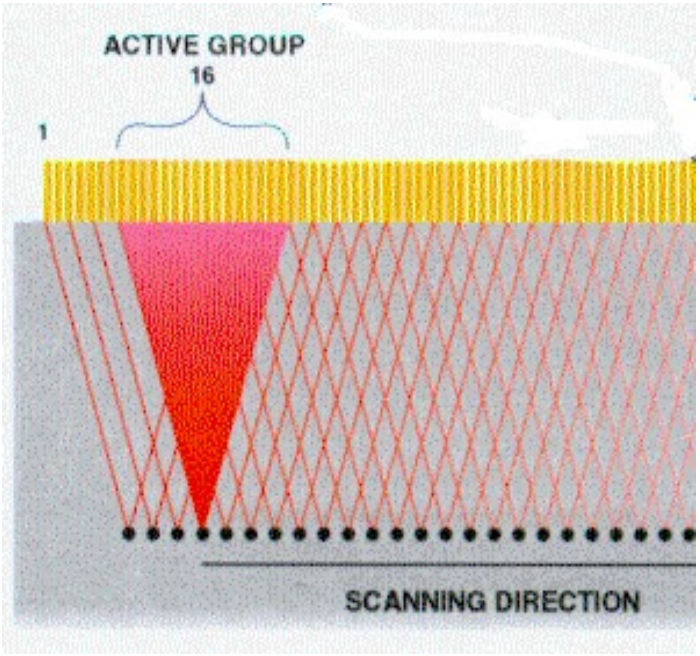
Electronic Scanning

- The ability to move the beam along one axis of an array without any mechanical movement.
- The movement is performed only by time multiplexing the active element group
- The beam movement depends on the probe geometry and could be:
  - linear scanning
  - sectorial scanning
  - lateral scanning
  - combination



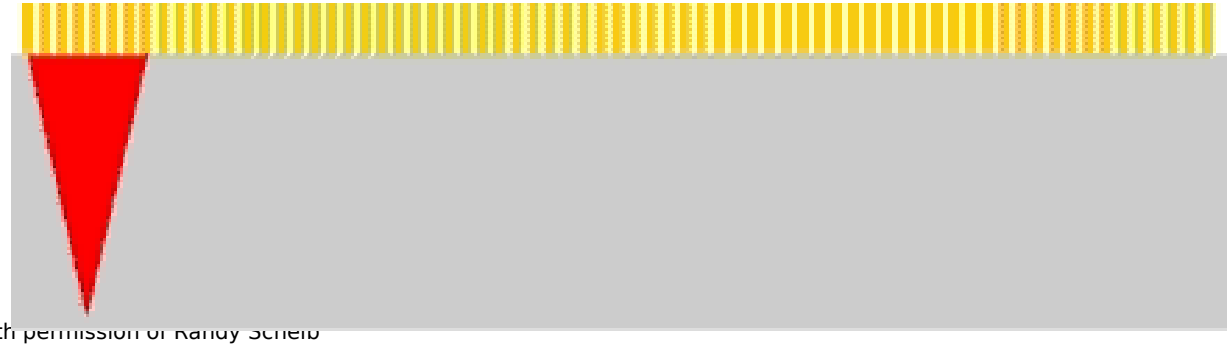


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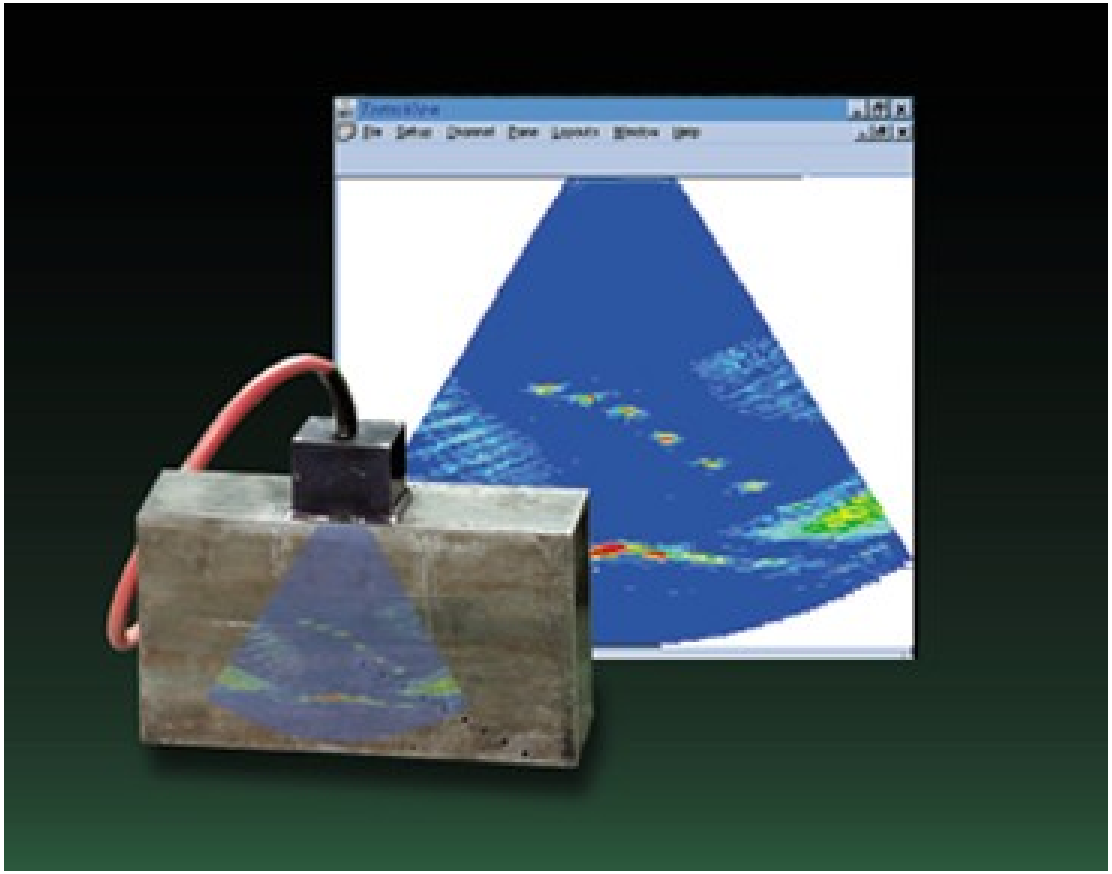
Illustration of Sectorial Scanning



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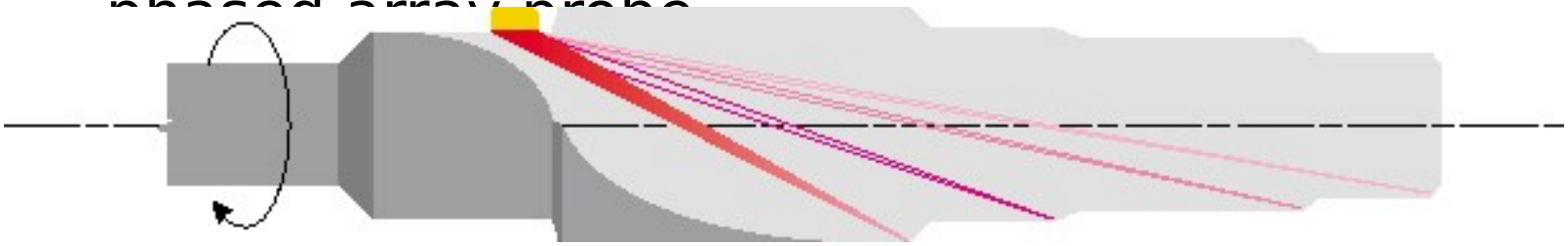
Sectorial Scans (S-scans)

- Sectorial scanning is the ability to scan a complete sector of volume without any probe movement.
- Useful for inspection of complex geometries, or those with space restrictions
- Combines the advantages of a wide beam and/or multiple focused probes in a single phased array probe



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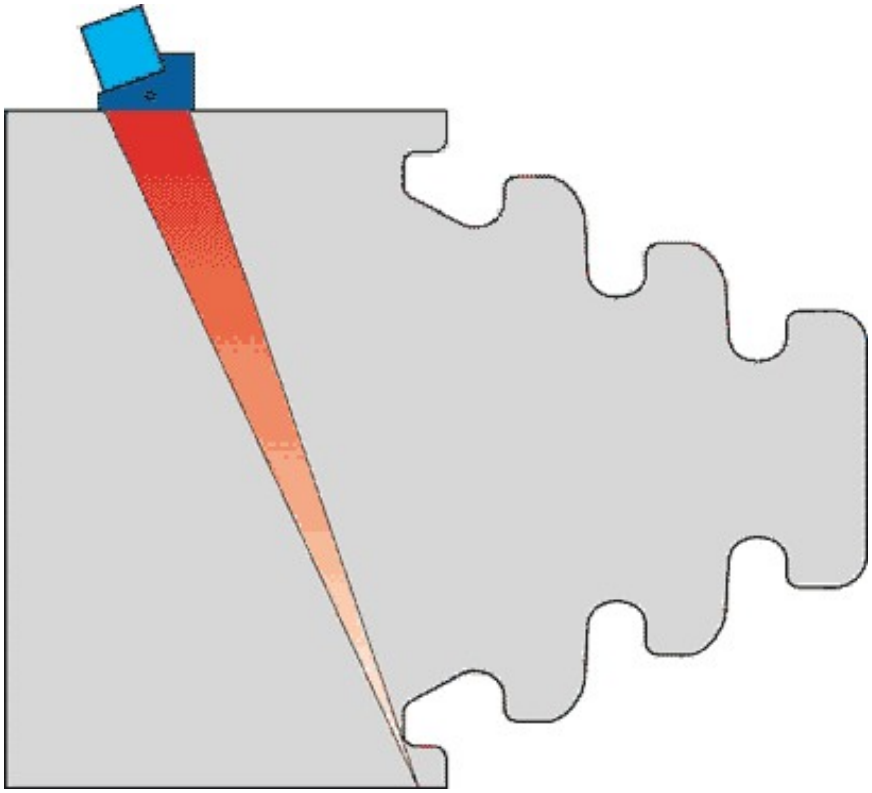
Sectorial Scanning Animation

- This illustration shows a turbine blade root being inspected using S-scans.



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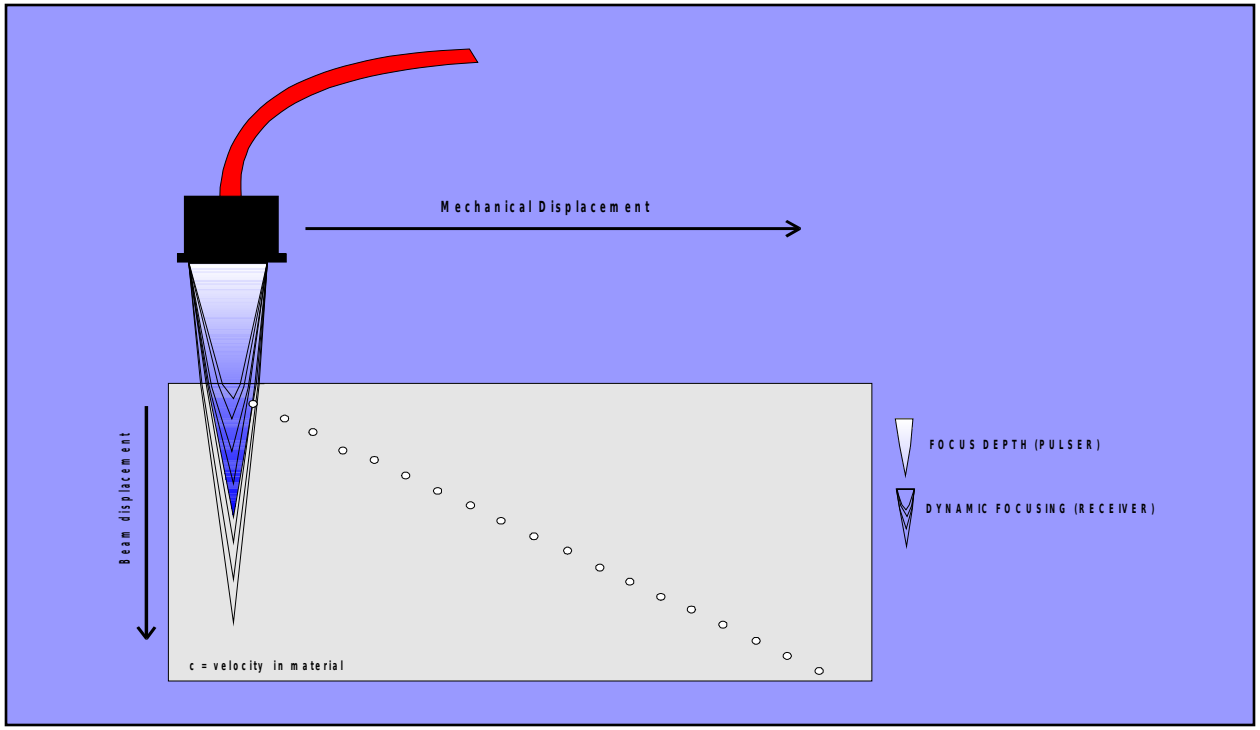
Schematic Representation of Dynamic Depth Focusing



DDF is an excellent way of inspecting thick components in a single pulse. The beam is refocused electronically on its return.

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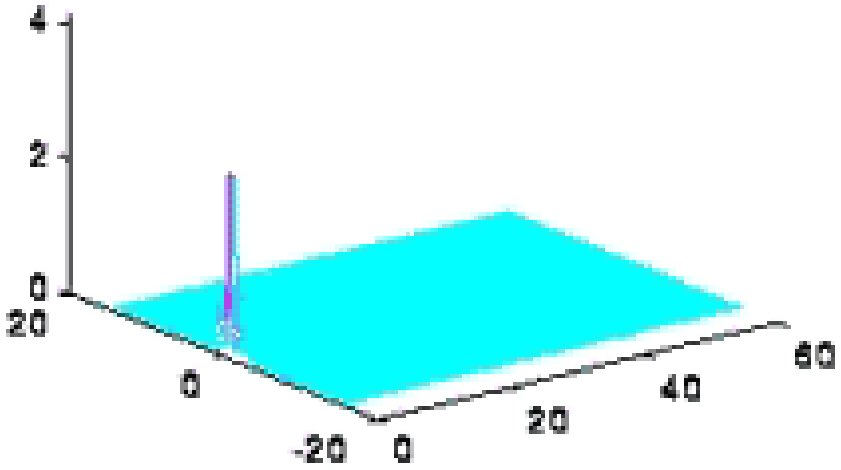
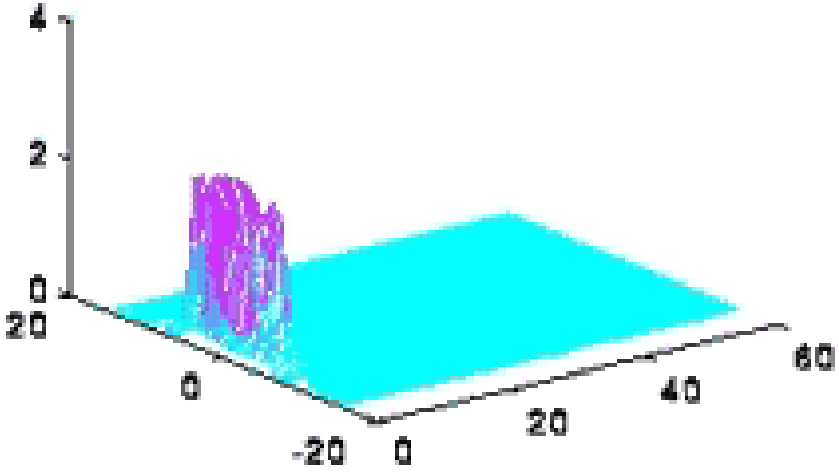
Dynamic Depth Focusing Animation





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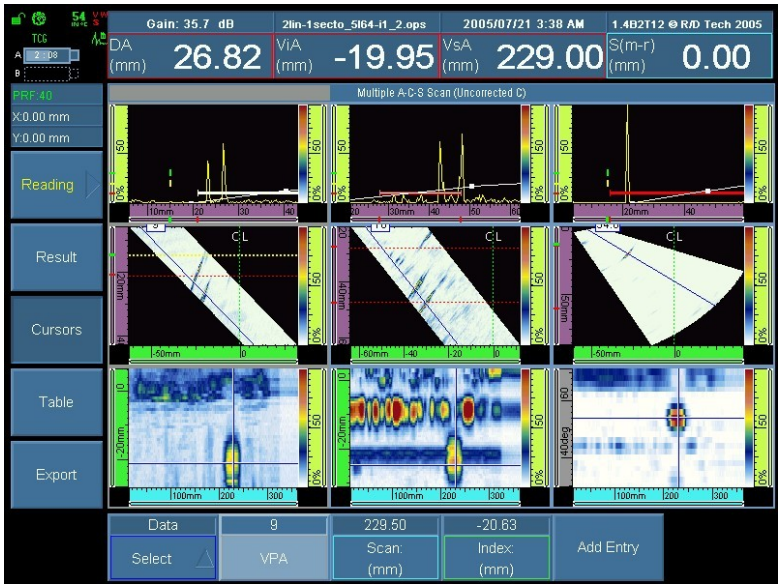
Perform Demonstration

Portable Phased Array Applications

- Austenitic weld inspections
- Turbine root inspections
- Butt weld inspections
- T-weld inspections of bridge structures
- HIC – Hydrogen Induced Crack
- Flange corrosion under gasket
- Nozzle inspections
- Bridge bolt inspections
- Spindle/shaft inspections
- Thread inspections
- Landing gear inspections
- Laser weld inspections
- Composites



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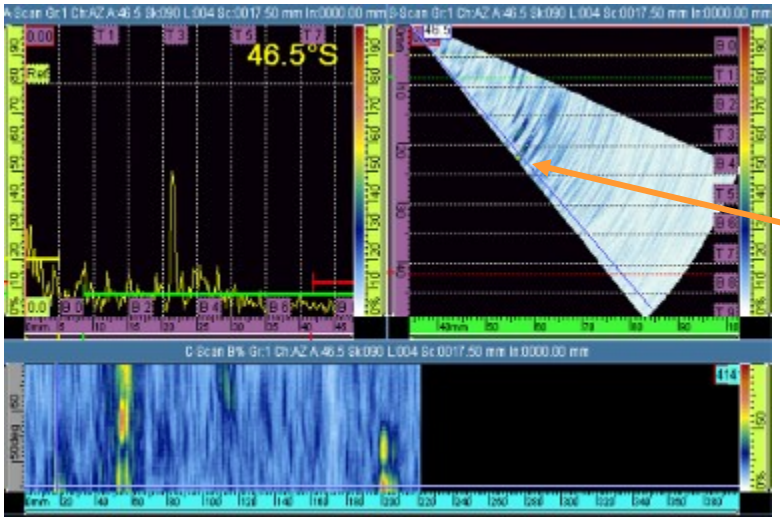
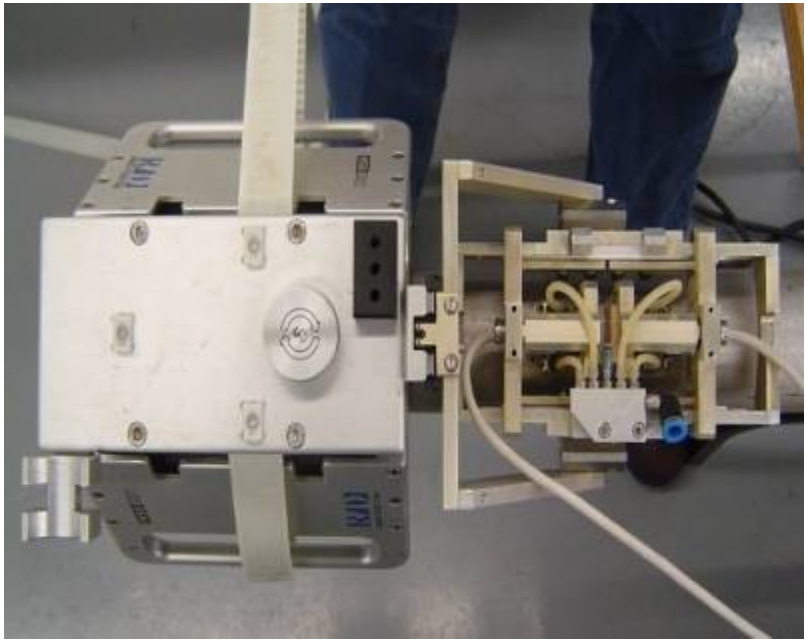
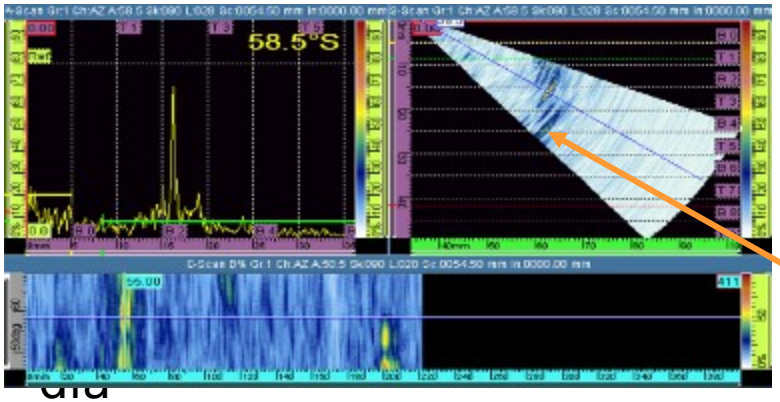
Construction Welding: Inspection of Small Diameter Austenitic Piping

- OmniScan PA instrument, two 5MHz 16 element probes using a splitter/umbilical, and a mechanical scanner.



1.5mm hole on near side of the weld





ID notch on the weld centerline

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Construction Welding: Fillet welds

Construction and maintenance of bridge structures

- Manual inspection using one small phased-array probe
- Linear scan at ~25 mm/s, one side at a time
- Inspection with 40- to 70-degree refracted angle
- Real-time display of S-scan and A-scan
- Accurate depth measurement of fillet welds

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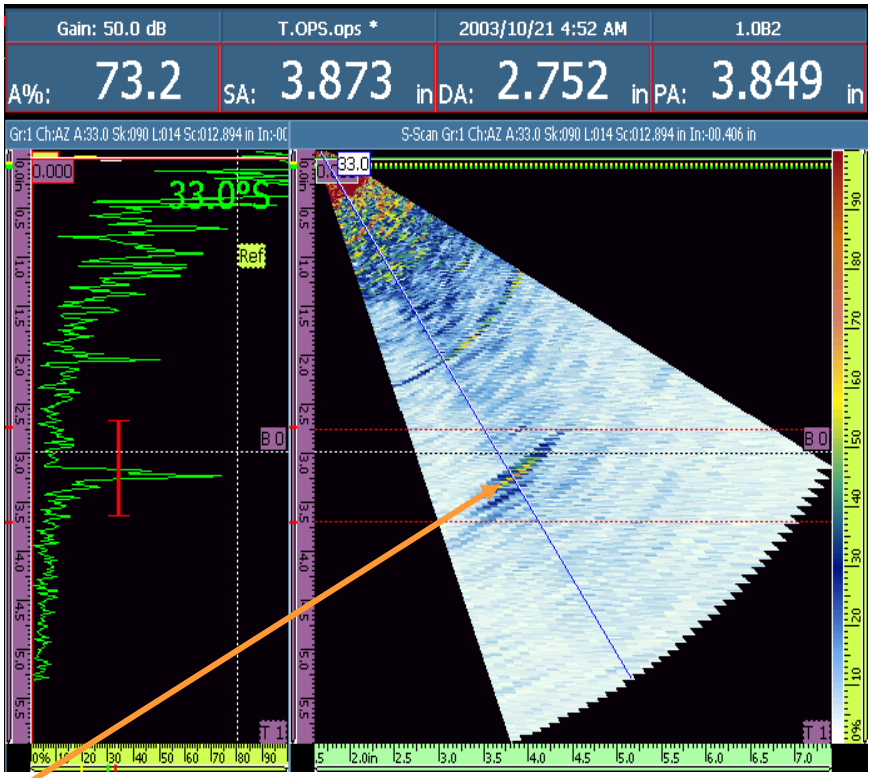
Construction Welding: Sample crack and S-scan image



Corner Crack

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OmniScan for Pipeline Welds

- Works with manual scanner
- All data saved
- Perform a scan line for each linear angle

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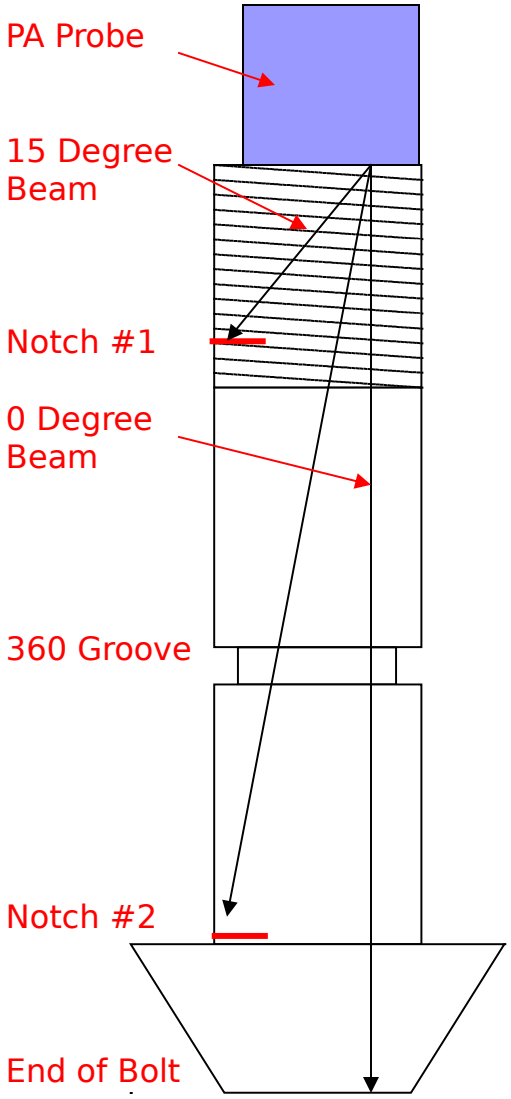
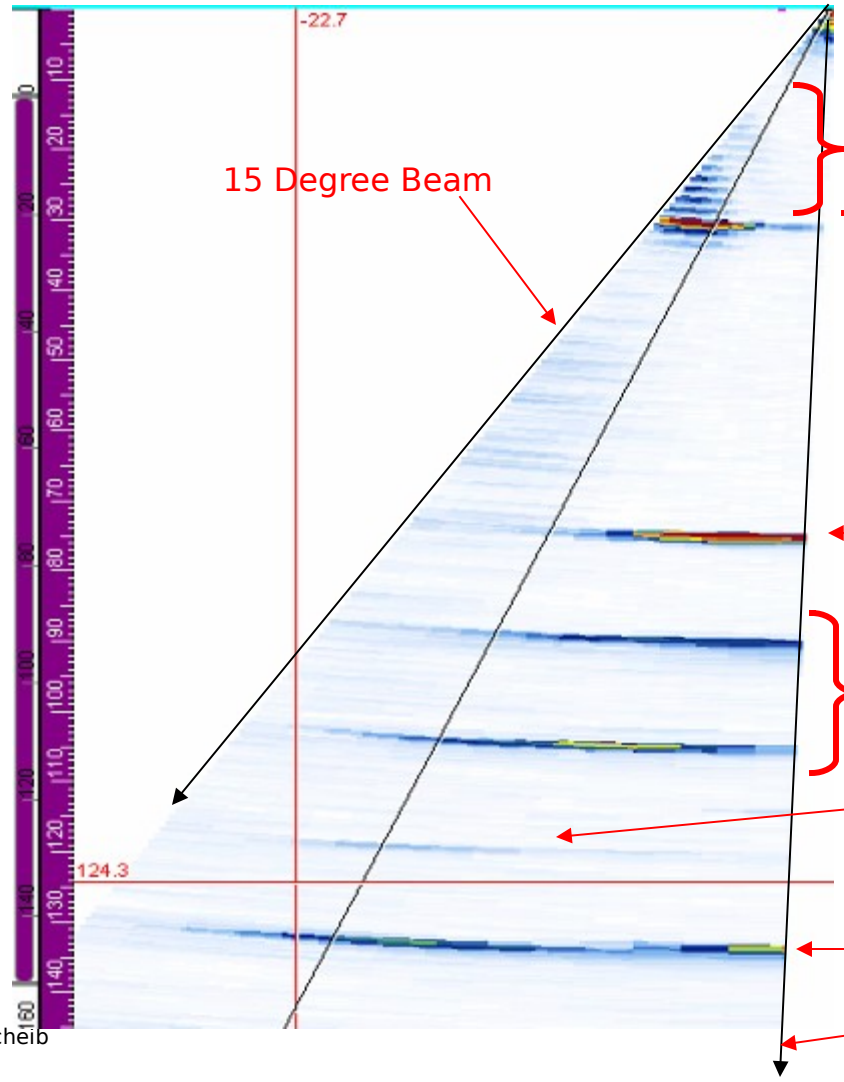
Bolts - PA Sectorial Scan





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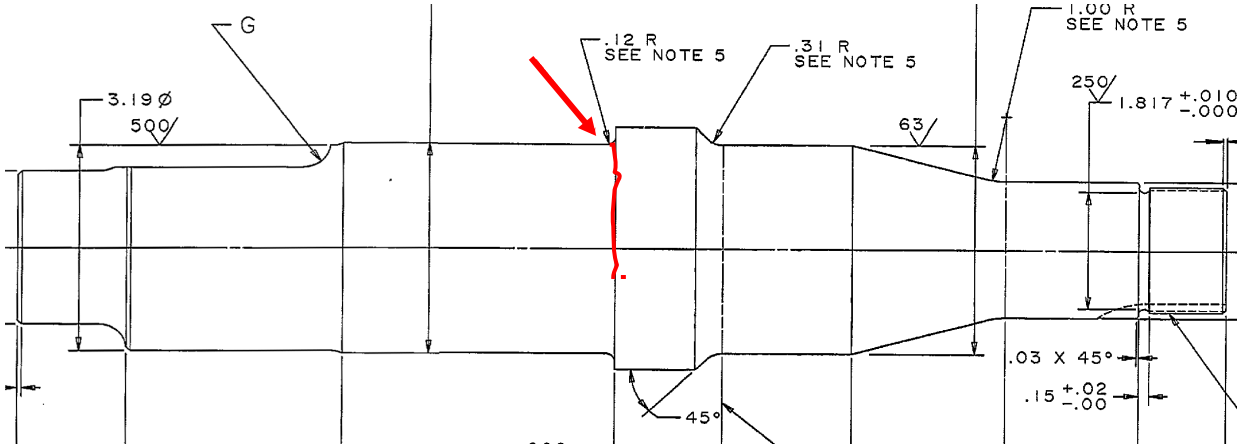
Road Arm Spindles / Shafts

Pictures from the field showing the broken road-arms on the vehicle



Road Arm Lower Spindle

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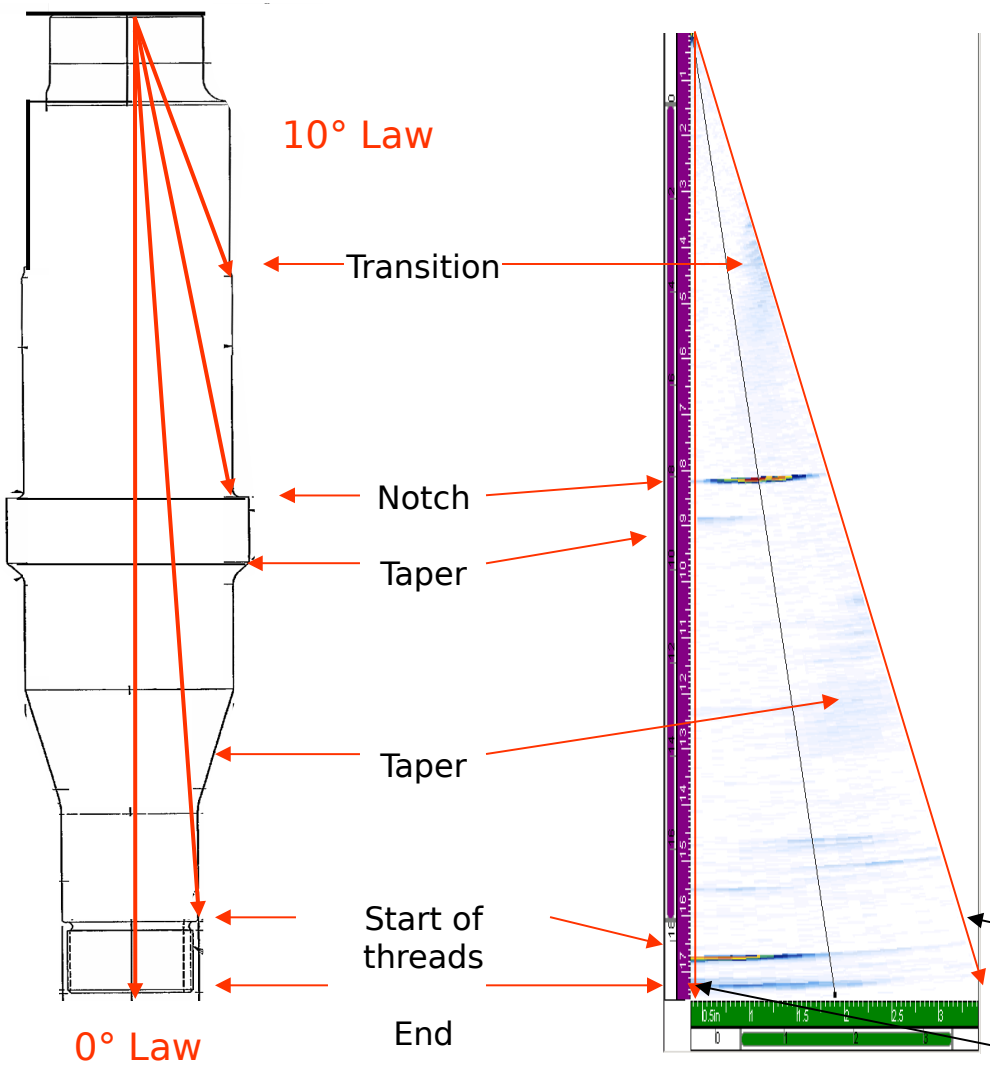
Road Arm - Global View



10 MHz Volume corrected Sectorial scan from 0º to 10 º

16 Elements, Pitch 0.4mm

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Component Testing : Thread inspection

- Very quick scanning and “go no-go”

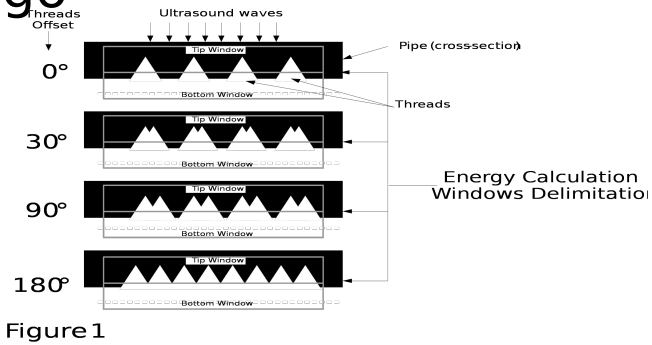
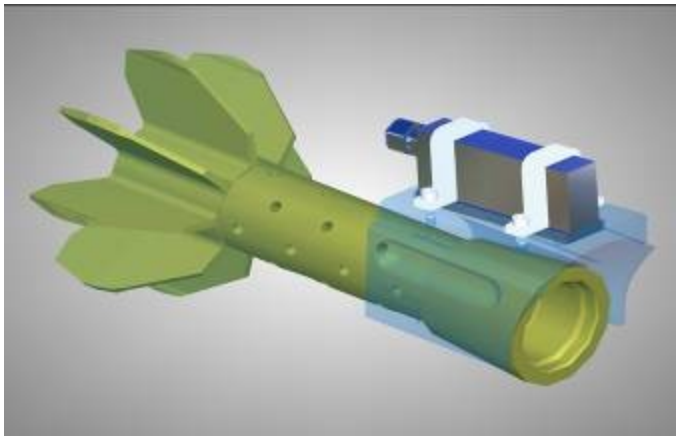
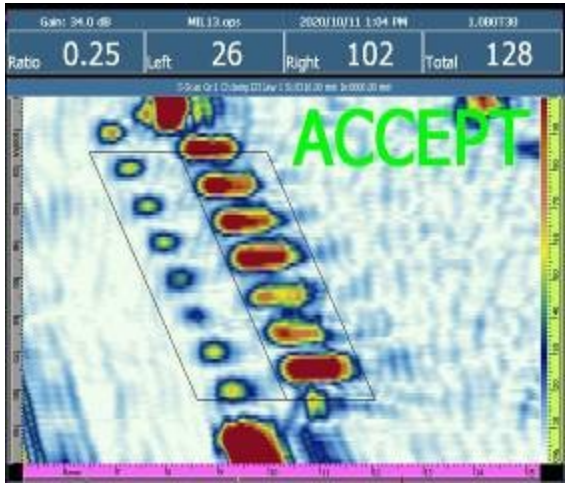


Figure 1



amplitude pattern thread assessment



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Aerospace: Landing gear inspection

Phased arrays offer major cost savings over MT.

- Manual inspection using one small phased array probe
- Linear scan ~12 mm/s
- Inspection using 40 to 65° refracted angle
- Real time display of A-scan, B-scan and S-scan
- Storage of linear scan for analysis.
- Less than three hours vs. a minimum of 1 week.

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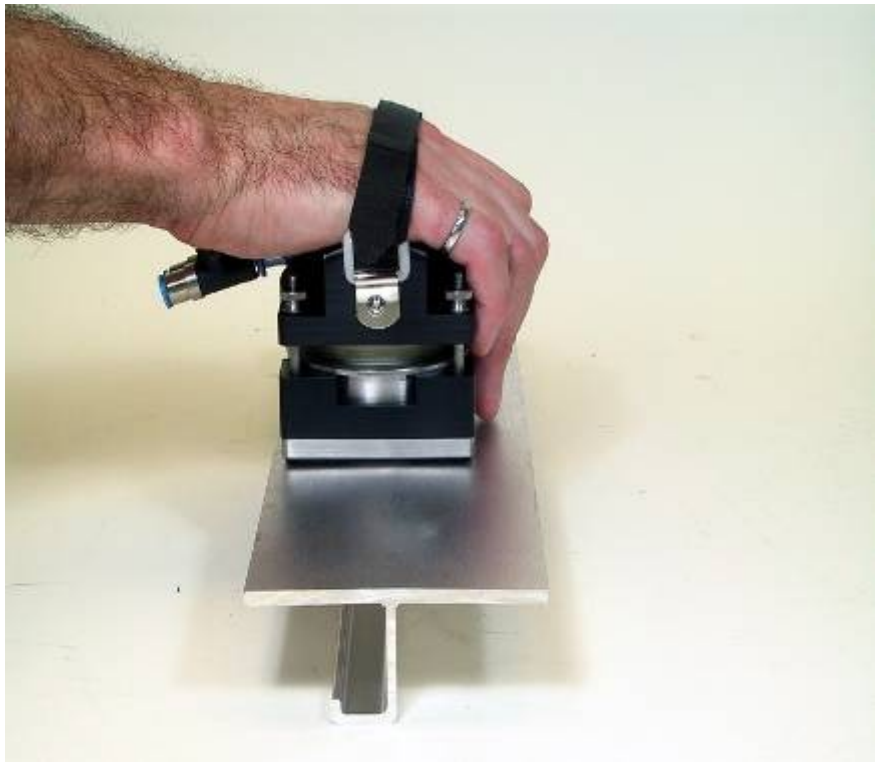
Aerospace: Laser Weld inspection



In-construction inspection of laser welding with phased array.

- Manual inspection using encoded water box and pre-focused phased array probe
- Linear scan of 10m in single scan at ~25 mm/s
- 0º electronic scanning
- Real time display of C-scan display
- Storage of C-scan data for analysis

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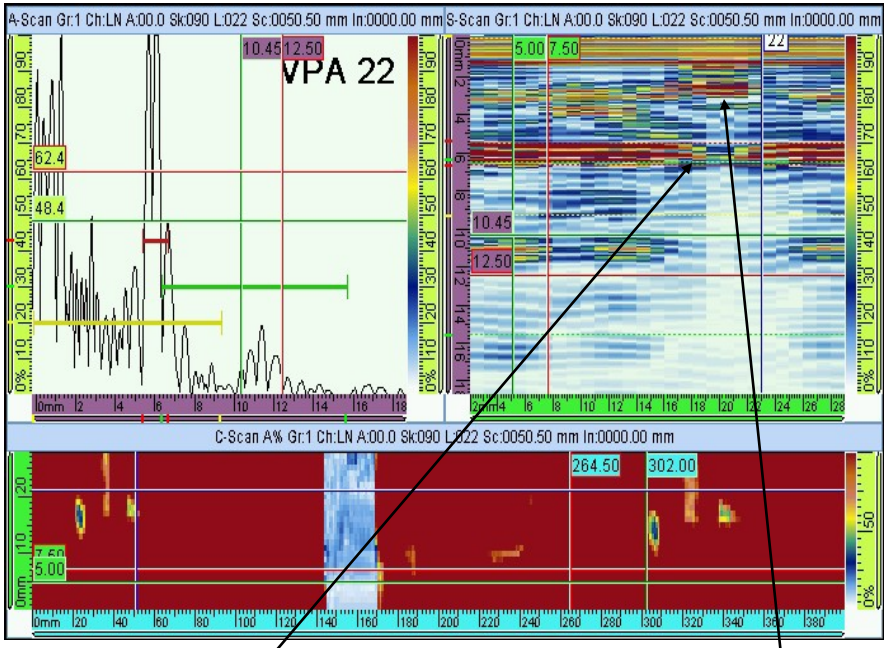
Aerospace: Composite inspection

- Carbon composite exam 6mm thick.
- Sample simulates lay-up tape commonly found during the manufacturing process.


A-Scan Gr:1 Ch:LN A:00.0 Sk:090 L:022 Sc:0050.50 mm In:0000.00 mm
S-Scan Gr:1 Ch:LN A:00.0 Sk:090 L:022 Sc:0050.50 mm In:0000.00 mm
VPA 22
C-Scan A% Gr:1 Ch:LN A:00.0 Sk:090 L:022 Sc:0050.50 mm In:0000.00 mm

Instant C-scan and S-scan – Note: Backwall dropout and near surface flaw

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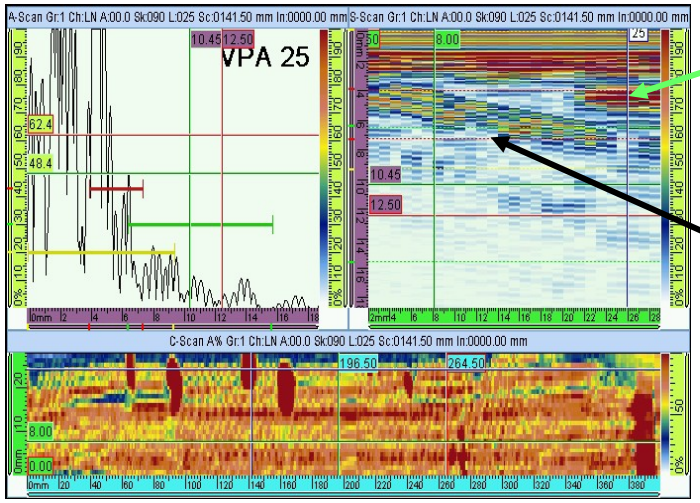
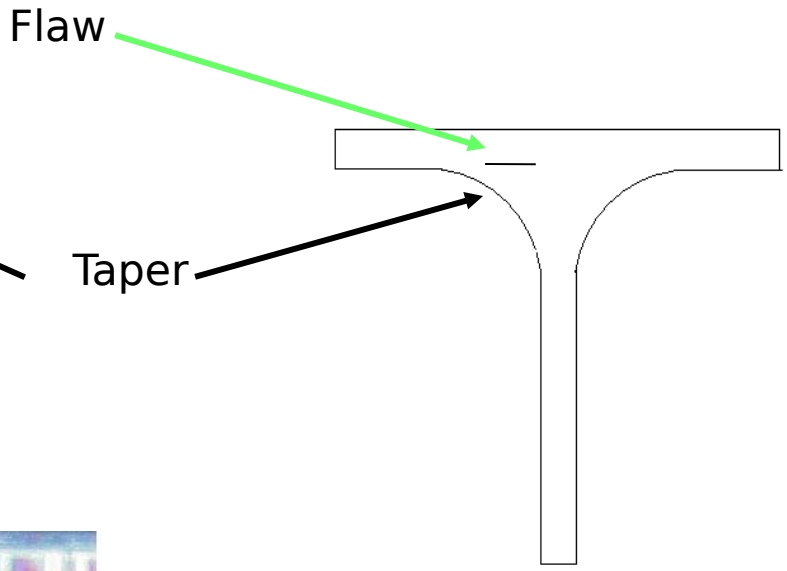
Aerospace: T-Joint Composite


A-Scan Gr:1 Ch:LN A:00.0 Sk:090 L:025 Sc:0141.50 mm In:0000.00 mm
S-Scan Gr:1 Ch:LN A:00.0 Sk:090 L:025 Sc:0141.50 mm In:0000.00 mm
VPA 25
C-Scan A% Gr:1 Ch:LN A:00.0 Sk:090 L:025 Sc:0141.50 mm In:0000.00 mm



The advantage with this inspection technique is speed and POD.

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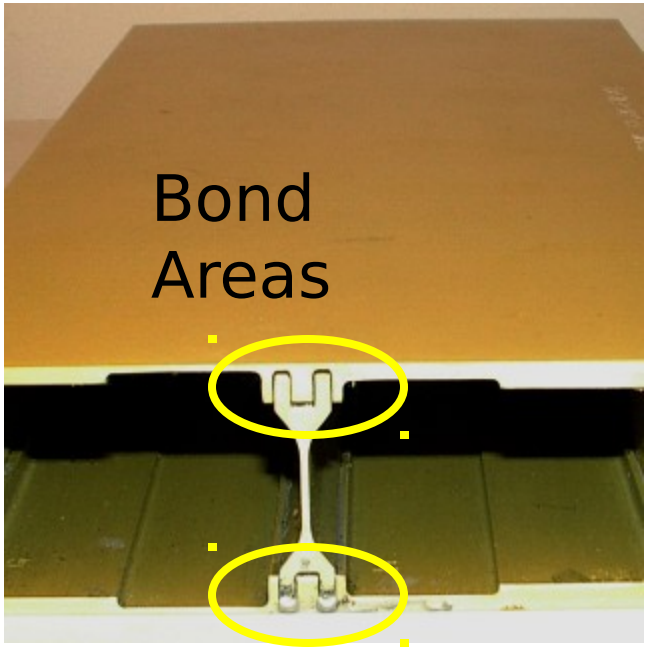
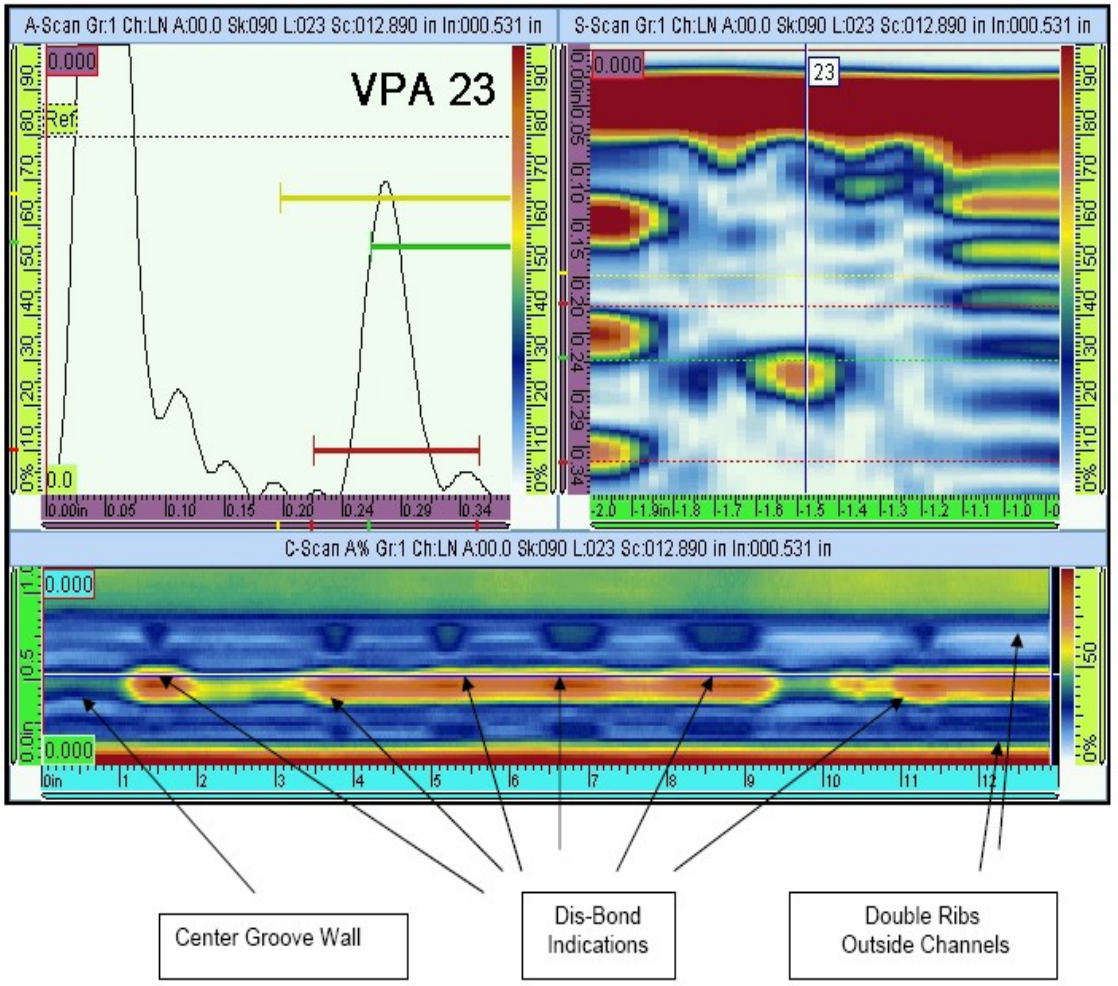
Aerospace: Aluminum to Aluminum Bond




A-Scan Gr:1 Ch:LN A:00.0 Sk:090 L:023 Sc:012.890 in In:000.531 in
VPA 23
S-Scan Gr:1 Ch:LN A:00.0 Sk:090 L:023 Sc:012.890 in In:000.531 in
C-Scan A% Gr:1 Ch:LN A:00.0 Sk:090 L:023 Sc:012.890 in In:000.531 in
Center Groove Wall
Dis-Bond Indications
Double Ribs Outside Channels

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Additional Applications

- Rail Thermite Welds
- Automotive Field
  - Replace mechanical failure analysis
  - Slug Weld C-scan Imaging
  - Spot Weld C-scan Imaging
- Component Testing
  - Braze Welds
  - Flaws

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Summary

- Many applications for portable phased arrays
- And more applications keep coming
- Advantages:
  - Speed
  - Imaging
  - Flexibility
  - Simplicity
  - Data storage
  - Reproducibility

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Thanks !

Any Questions?

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